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QUICK DECLINE OF CITRUS AS INFLUENCED BY TOP-ROOT RELATIONSHIPS

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A THREAT . . .

to the California Citrus Industry

In 1939, an unfamiliar disorder affecting orange trees appeared in a small number of orchards in two areas of Los Angeles County. Soon after that, it was discovered in Orange County. The striking character of the symptoms on affected trees resulted in the name "quick decline." A 1940 survey of the Los Angeles County Agricultural Department revealed 146 affected trees in seven orchards. Subsequent findings were: 1941, 277 affected trees in 21 orchards; 1942, 791 trees in 35 orchards; 1943, 1,894 trees affected; 1944, 7,484 trees. By 1949, there were about 200,000 affected trees in Los Angeles County. The disease also spread over a large part of Orange County, and to many orchards in San Bernardino County. Some infected trees were found in western Riverside County in 1949, and in southern Ventura County in 1951. An estimated half million trees have been affected as of 1952.

In California there are approximately 250,000 acres of oranges and grapefruit, or about 22 million trees. Of these, it is estimated that from 40 to 50 per cent—$8\frac{1}{2}$ to $10\frac{1}{2}$ million trees—have top-root combinations that are susceptible and may eventually be affected. Clearly, this disease may be expected to have a serious effect on the economy of the citrus industry in California and to cause major adjustments in it.

The cover picture shows two Valencia trees on sour orange root. The one at the top has the "collapse" type of quick decline symptoms. The tree in the lower photograph shows the "gradual decline" type symptoms. (See page 8.)

THE PROBLEM:

Will the right top

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A PROGRESS REPORT . . .

on What Is Being Done about It

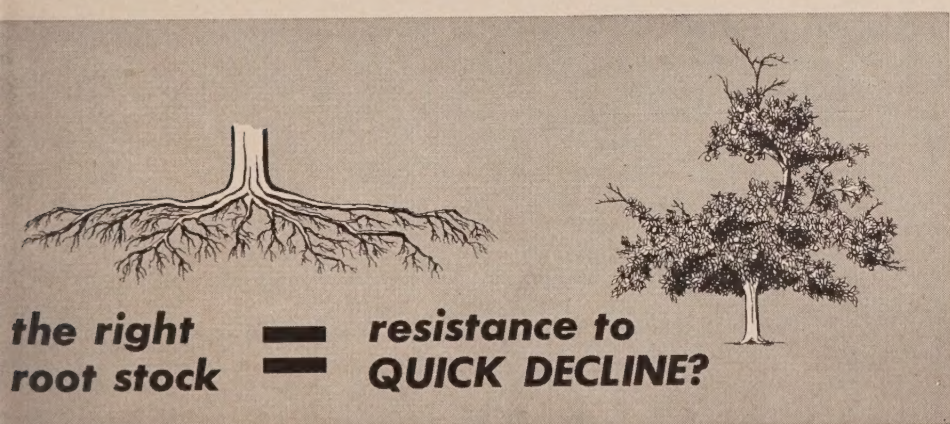
RESEARCH ON quick decline is a continuing project. This bulletin, the first of a series of progress reports, includes a history of the disease and studies of the tolerance of the commercially important scions to quick decline when those scions are budded on a wide range of species and varieties of rootstocks. Experiments on alterations in the top and root relationships of established trees are also described.

Briefly, this is what research, to date, has contributed toward solution of the problem of quick decline:

It is now known that quick decline is a virus disease, and that the virus is transmitted from tree to tree by an insect vector. Only certain budded combinations, and occasionally seedlings, are affected. Quick decline is probably identical with diseases long prevalent in South Africa and Java, with the "bud union decline" of Australia, and the "tristeza" disease of Argentina and Brazil. The disease has been particularly devastating to the citrus industry in the two South American countries because their orchards were planted chiefly with susceptible combinations.

In rootstock experiments of limited scope, with plantings in 1945 and 1946, trees were subjected to natural infection as well as artificial inoculation with the quick decline virus. A more comprehensive experiment, with Valencia orange scions on 125 different rootstocks, was planted in 1948. Half of the trees in this second planting were subjected to inoculation by the spur-bud technique. Generally, present results of the two trials agree: the same combinations showed symptoms in both plantings. However, after-inoculation symptoms progressed more rapidly in the Baldwin Park plantings. (See table 1, page 12.)

Inoculation by means of diseased buds generally caused a reduction in tree growth



proportionate to the symptoms in evidence although there were exceptions. In some cases, the growth was reduced in trees which showed no other visual symptoms.

Susceptibilities

Trees on the various rootstocks were classed as tolerant, susceptible, or uncertain in their reaction to the disease. The following designations generally hold true as of August, 1950:

Sweet orange scions are apparently *susceptible* to quick decline when budded on stocks of sour orange, shaddock, hybrids of shaddock × sweet orange, grapefruit, all lemons (except Rough lemon types), some mandarin hybrids (mostly tangelos), *Citrus Ichangensis* hybrids, Palestine sweet lime, and *Citrus macroptera.* Stem pitting has appeared on Morton citrange stock.

Based on the effects of artificial inoculation, the reaction of sweet orange scions is *uncertain* on stocks of trifoliate orange, trifoliate orange hybrids, some mandarins, many mandarin hybrids, and some sweet oranges.

Sweet orange scions appear to be *tolerant* on stocks of the acid and mandarin limes, some mandarins, on several mandarin hybrids, on some sweet oranges, on Rough lemon types, and on *Citrus moi.*

In some cases, the determination of tolerance or susceptibility is clear. In others, not enough time has elapsed for proper classification.

Generally, the effects of artificial inoculation are apparent, but in some cases their duration is not yet known. Observations will be continued, to clarify results.

Topworking

Topworking susceptible sweet orange trees to lemons was generally successful even when some of the trees were showing symptoms of the disease at the time. It was found that all of the orange top should be removed in topworking.

Topworking to grapefruit was unsatisfactory. Grapefruit/sweet orange/sour orange was found susceptible to quick decline.

Inserting a tolerant interstock into susceptible trees did not prevent occurrence of the disease; in fact, it seemed to hasten the development of symptoms.

When the top was susceptible on a particular rootstock, the top remained susceptible when the species used for the root was inserted as an intermediate stock over a normally tolerant stock.

Inarching

Inarching of susceptible combinations with tolerant seedlings did not prevent progress of the disease in infected trees.

The growth of the inarches and the vigor of the tops were increased by various girdling procedures. A complete girdling, or an inverted "funnel" between the inarches, resulted in the greatest inarch growth.

Rough lemon seedlings, when used for inarching, gave better results than did sweet orange seedlings.

When inarched trees were heavily pruned, they formed a new top which was normal in appearance. The top volume of these trees five years after inarching and three years after top pruning did not exceed the size of young trees on tolerant roots planted at the time of inarching.

It appears that the replanting of tolerant combinations is thus more practical than inarching.

The following pages contain a detailed discussion of the experiments and the results obtained, with supporting illustrations and tables.

QUICK DECLINE of CITRUS
As Influenced by
TOP-ROOT RELATIONSHIPS[1]

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Importance of Top-root Relationships to Quick Decline

As early as 1944, Halma, Smoyer, and Schwalm (*30*)[2] observed that tops of sweet orange (*Citrus sinensis* Osb.) on sour orange (*Citrus aurantium* Linn.) roots appeared to be affected by quick decline, while sweet orange tops on sweet orange roots appeared to be resistant. The following year, these same workers published additional observations (*31*) suggesting that sweet orange trees on roots of trifoliate orange, grapefruit, and Rough lemon were also resistant combinations. They further reported, on the basis of limited observations, that lemon trees were not affected by the disease.

In foreign countries, studies of citrus diseases that closely resemble quick decline (*2, 25, 39, 54, 55, 57*) have shown that sweet orange and some other top species are susceptible on other roots in addition to sour orange. The importance of top-root relationships in determining susceptibility is thus well established.

Although a citrus variety, as a rootstock, may be tolerant to quick decline, it may still be undesirable since all rootstocks do not have the same horticultural value. They vary in their resistance to diseases other than quick decline, their ability to grow as replants in old citrus soils, and their wide effects on scion varieties budded upon them. Many of the citrus species and varieties included in these trials have never previously been tested for their desirability as stocks. It is important, therefore, that tolerant roots not have a deleterious effect on the longevity of the tree or an undesirable effect on fruit yields and fruit quality of the scion variety budded upon it.

Relation of Quick Decline to Similar Diseases Elsewhere

A disorder very similar to quick decline was first observed in South Africa as early as 1899 (*16, 45*). In 1891, several members of the Cape Department of Agriculture, recognizing the merits of sour orange rootstock in foreign countries (*38*), advocated that citrus varieties in South Africa be budded on sour orange stock. Of the trees so budded, only those with lemon tops remained healthy after a few years; the others became sickly and died. The failure of trees on sour orange roots was investigated by a Commission of Inquiry of the Cape Department of Agriculture, in 1904 (*4*),

[1] Paper No. 744, University of California Citrus Experiment Station, Riverside, California.
[2] Italicized figures in parentheses indicate references to "Literature Cited," page 33.

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which found that most of the healthy trees in South Africa had been budded on Rough lemon (*C. limon* hybrid) stock. The failure of sour orange stock in South Africa was originally attributed to "incompatibility."

A malady resulting in the same general symptoms was next observed in Java, about 1928, by Toxopeus (*55*). By the use of reciprocal grafts of sweet orange, sour orange, and Japanese citron (*Citrus reticulata* hybrid), he showed that the use of a tolerant intermediate stock neither prevented nor delayed the decline. As long as the top was sweet orange and the stock or interstock was sour orange, the combination failed. Toxopeus further showed that the parallel insertion of both sweet orange and Japanese citron tops into sour orange roots results in death of the plants. Inarching sweet orange trees with sour orange or Japanese citron seedlings resulted only in the failure of the trees with sour orange inarches. Toxopeus suggested that the sweet orange top produced some substance that was toxic to the sour root.

About 1931, a similar disease appeared in Argentina (*5*). The trouble was reported in Brazil in 1937 (*5*). Moreira (*42*) referred to it as the "tristeza" disease (*tristeza*, in Portuguese, means melancholy or sadness), and described its very rapid spread. Bitancourt (*6*) proposed that an infectious agent was involved as the cause of the disease in Brazil. Orange, grapefruit, and mandarin scions on sour orange root declined, but sour orange seedlings or lemons budded on sour orange roots remained healthy. Moreira (*42*) reported that sweet orange tops on Thornton tangelo stock were affected by the disease, but that the Sampson tangelo was completely tolerant when used with sweet orange tops. However, Marloth (*39*), in studies made at Nelspruit, Transvaal, reported the behavior of Sampson tangelo root budded to sweet orange to be similar to that of sour orange. Bertelli and Bertelli (*3*) reported the presence of tristeza in Uruguay in 1940. It was suspected in Venezuela in 1949 (*11*).

The same, or a very similar, disease was first noticed in Australia, about 1941 (*10, 34*), where it has been called "bud-union decline." It is also found in New Zealand (*34*), on the Gold Coast of West Africa (*24, 32*), where it is prevalent on lime trees, and in Ceylon (*47, 48*). It is also believed to be in China (*53*, and unpublished information from Dr. Lin Kung-Hsiang, Professor of Plant Pathology, Lingnan University, Canton, China), Mexico, and other countries. A disorder resembling quick decline has recently been reported in Louisiana (*8*). In 1952 it was reported from Hawaii (*23*) and also from Florida (*9*). Evidence has been presented recently, by McClean (*36, 37*), that the condition known as "stem-pitting" of grapefruit in South Africa is probably a different symptom manifestation of the disease that causes the failure of sweet orange trees on sour orange roots. The observations of Grant, Costa, and Moreira (*14, 28, 29*) on tristeza, and of Wallace and Drake (*56*) on quick decline substantiate this fact.

Nature and Transmission of Quick Decline and Similar Diseases

Although several theories as to the cause of quick decline and of similar, if not identical, diseases elsewhere were advanced and investigated (*12, 22*), the possibility that these diseases would prove to be of virus origin appeared most probable (*5*). This theory was thoroughly analyzed by Webber (*57*), in 1943, for the diseases then prevalent in South Africa and in Brazil. Subsequent research has proved the virus nature of the disease. Schneider (*22*) investigated the anatomical relationships in trees affected with quick decline. He found a necrosis of the sieve tubes, just below the bud union, which appeared to precede any other symptom, and pointed out that a

similar necrosis was caused by a virus in the case of cherry trees affected with the "buckskin" disease (*46, 49*). The similarity of the pathological anatomy of quick decline and of tristeza-affected orange trees was later established by Schneider (*51*) and Schneider, Bitancourt, and Rosetti (*52*). McAlpin *et al.* (*34*) indicated similar results with bud-union decline in Australia.

The virus nature of quick decline was first demonstrated by Fawcett and Wallace in 1946 (*20*). These workers showed that transmission of quick decline could be effected by inoculating healthy trees by insertion of buds from trees showing symptoms of the disease, and concluded that bacteria or fungi were not involved (*20, 22*). Subsequently, Meneghini (*41*) succeeded in transmitting tristeza by means of an insect vector, and concluded that this disease also was caused by a virus. Bennett and Costa (*1, 2*) transmitted tristeza by infected buds and the vector. Oberholzer (*44*), in 1947, reported the tissue transmission of the disease present in the Union of South Africa. He also showed that susceptible combinations (for example, sweet orange tops on sour orange roots, both derived from seedlings) remained healthy when grown in a greenhouse free of insect pests. The virus causing the disease is apparently not seed transmitted (*2, 44*).

In 1948, Fawcett and Wallace (*21*) demonstrated that sweet orange tops on sweet orange roots are symptomless carriers of the quick decline virus. Bennett and Costa (*2*) were able to transmit the virus of tristeza from symptomless sources, such as sweet orange on Rangpur lime, Rough lemon on its own roots, "cravo" tangerine on its own roots, and an unidentified citrus on its own roots. Perhaps any variety of citrus that does not show obvious symptoms of the disease when infected may serve as a host and act as a carrier. Budded trees have shown the most severe symptoms. Milder symptoms have been observed on some inoculated seedlings (*2, 27*), but the condition of such seedlings later improved. It is now recognized (*56, 28, 29*) that certain citrus seedlings are good indicator plants for the presence of the virus.

Infection in nature and the resultant rapid spread of these diseases have been attributed to insect vectors. Meneghini (*41*), in 1946, and subsequently Bennett and Costa (*2*) demonstrated that tristeza virus could be transmitted by a species of black aphid, *Aphis citricidus* (Kirk.). This aphid has not been found in the United States. McAlpin *et al.* (*34*) intimated that either red scale (*Aonidiella* sp.) or the black aphid was a vector for bud-union decline. In 1949 (*35*) he concluded that the citrus aphid (*Aphis citricidus* Kirk.) acts as a vector, but presented no data. This aphid has also been shown to transmit the causal virus of the disease on limes on the Gold Coast (*32*), stem pitting of grapefruit in South Africa (*36, 37*), and stem pitting in Brazil (*14*). In California, Dickson and his coworkers showed that *Aphis gossypii* Glover is a vector of the quick decline virus (*17, 18*). Wallace and Drake (*56*) have demonstrated that this aphis is also capable of transmitting the quick decline virus and causing stem pitting symptoms on West Indian lime seedlings. Thus the importance of insect carriers of the causal viruses of these diseases is well established.

It has not always been conceded that quick decline, tristeza, and other "tristeza-type" disorders are identical. However, as a result of the recent investigations of Hughes and Lister (*32*), McClean (*36, 37*), Costa, *et al.* (*14*), and Wallace and Drake (*56*), the evidence now appears conclusive that these diseases are caused by the same virus or by closely related strains. This conclusion was reached on the basis of the marked similarity of symptoms on budded trees and on Mexican lime seedlings, and the transmission of the causal virus of all

these diseases (except quick decline) by *Aphis citricidus.* This species has not been found in the United States. The slower rate of spread of the quick decline disease in California may be partly due to a low efficiency in virus transmission by *Aphis gossypii* and the local effects of climate upon the geographical distribution of that vector.

Recent evidence (*26*) also indicates that there are different strains of the tristeza virus, and that they differ in virulence. A difference in virulence might reasonably account for some differences in various top-root responses (*25, 27*) under similar environmental conditions. Top-root responses may also possibly vary because of wide differences in environmental conditions.

Various citrus varieties are used as tops and roots in different countries. Apparent conflicts in the susceptibility of specific combinations may be due to any one, or a combination of, the above factors.

SYMPTOMS OF QUICK DECLINE

Symptoms of quick decline may be divided into two types—with one, trees show a relatively gradual decline; and with the other, trees show collapse or abrupt wilting (cover picture). Although the latter type is the most striking in appearance, and justifies the name quick decline, it is the less common.

Gradual Decline. The first visual symptom of the more gradual decline of old orchard trees is the suppression of the normal seasonal flushes of growth. This lack of growth is usually accompanied by leaf discoloration. The leaves on affected trees lose their dark green luster and become dull and olive-green to yellow-green in color. Early in the spring or late in the fall the leaves usually become somewhat yellow and display some yellowing of the midrib and the lateral veins. The new leaves on affected trees are small, leathery, and stand somewhat erect. After leaf discoloration begins, the leaves are shed gradually and the branches begin to die back from the tips. As the limbs become defoliated, weak multiple shoots develop from dormant buds, but there are no strong leaders. Such trees may survive for several years. They are incapable of bearing a commercial crop and are generally promptly removed from the orchards.

Collapse. When affected trees collapse, an abrupt wilting of the leaves occurs within a period of a few days. This may or may not be preceded by initial symptoms similar to those that characterize trees affected with the gradual decline. The dried leaves and fruits generally remain attached to the twigs for several weeks or longer. Although such trees at first appear to be dead, they frequently develop new shoots from buds on the large limbs or trunk. The new growth consists of weak multiple shoots, and is not vigorous. Such trees then enter a stage of partial recovery, sometimes referred to as an equilibrium stage. Light crops of inferior quality fruit may then be obtained. The trees may again collapse during periods of soil moisture stress.

Diseased trees have a tendency to blossom very heavily, and the bloom may occur in off seasons. The number of fruits set is larger than normal, and there is a tendency for the fruits to be borne in clusters. The orange fruits color prematurely, and appear more conspicuous. Heavy or off-season bloom and abnormally heavy crops of prematurely colored fruit are sometimes the first visible indications of the disease.

Among the earliest symptoms that can be observed on affected trees is the dying of the feeder roots, followed by the death and sloughing of the bark of the smaller lateral roots (*22*). These effects precede or accompany the appearance of top symptoms. The injury to the root system follows the necrosis of the sieve tubes of

the rootstock below the bud union. These tubes are blocked (*50*), thus preventing movement of carbohydrates to the root system. As the reserve supply of carbohydrates in the roots is utilized, starch disappears—first in the feeder roots (*19*, *22*). When these have been entirely depleted of starch, they soon decompose (*22*). Some functioning phloem usually persists or is formed, however, and slight root activity generally occurs. The rate and extent of the destruction of the root system are associated with the degree of the severity of the top symptoms.

Application of the starch test (I–KI) to root tissues as an aid in the diagnosis of quick decline and of tristeza has been a subject of much discussion. In 1945, Fawcett (*19*) found that trees visibly affected by quick decline showed no starch in the wood or bark of live roots. This phenomenon was observed as an outgrowth of previous work by Bitancourt (*7*) on trees affected with tristeza disease in Brazil. In quick decline, the disappearance of starch from the wood or bark of live roots at their extremities, and frequently from the wood of larger live roots, may be detected prior to, or coincident with, the appearance of top symptoms. In the earliest stages of the disease, the amount of starch varies inversely according to the degree of severity of the top symptoms. However, Bitancourt (*7*) reported that tristeza top symptoms may appear before the disappearance of starch from the roots, and this is also said to be true of trees suffering from "chlorosis" in Ceylon (*48*). It should be emphasized that the starch test is merely an aid in the diagnosis of quick decline—used only to determine if the movement of the food supply has been interrupted. But this reaction could be caused by any type of girdling injury, such as gophering and gummosis, as well as by quick decline.

Stem Pitting. The stem pitting aspect of quick decline is another phase of the symptom complex. Stem pitting symptoms may or may not accompany typical quick decline symptoms. The term stem pitting is somewhat misleading since it implies that the disorder occurs

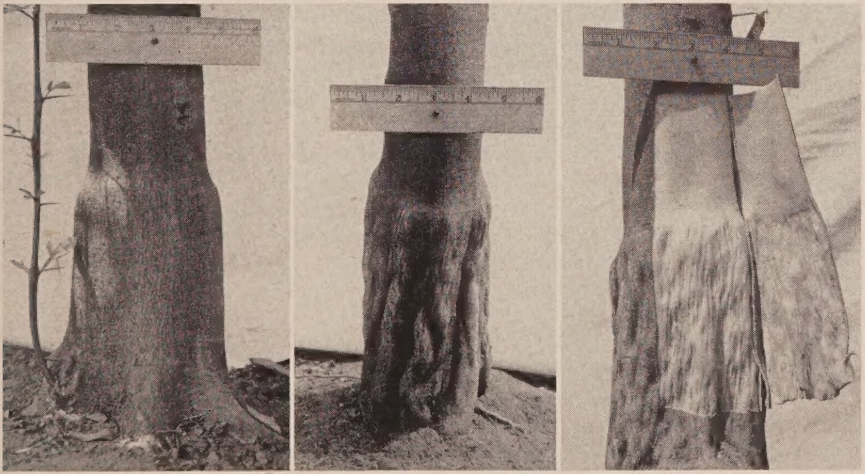

Fig. 1—Left: close-up of a healthy Morton citrange stock, showing its typical smooth, symmetrical nature. Center: close-up of a Morton citrange stock affected by stem pitting, showing the resulting grooves and asymmetrical nature of the trunk. Right: Morton citrange stock affected by stem pitting which did not extend across the bud union. Note pits and grooves in the wood and corresponding peglike growth on inner surface of rolled-back bark.

only on the stem. However, stem pitting is an anatomical abnormality which may occur on the twigs, branches, or trunk of citrus seedlings or budded trees, and on the latter it may also be found on the stock as a result of the plant's being infected with the quick decline virus. The top alone may show pitting in some combinations, the root alone in some, and both top and root in others.

Stem pitting is characterized by the inability of the cambium to function normally, at least in localized areas. Portions of the xylem (wood) fail to develop, or do not develop normally. This results in numerous small pits or depressions in the wood. In contrast, small masses of tissue develop in place of some of the normal phloem (bark) elements so that, corresponding to the sunken, undeveloped areas in the wood, are small, elevated, peglike growths on the inner surface of the bark (fig. 1, right). In advanced stages the pits tend to anastamose (connect), and the resulting striations, or grooves, tend to follow a twisted course parallel to the grain of the wood. The grooving may be more severe in some areas than in others, and may result in an asymmetrical shape of the stock (fig. 1, center). This symptom of quick decline first appeared in the field in 1952 and was more fully investigated in October of that year. Results are reported elsewhere.

OBJECTIVES AND PROCEDURE

The first purpose of the present study (of which this bulletin is a progress report) is to determine the tolerance or susceptibility to quick decline of the commercially important varieties of citrus when grown on a large number of species and varieties of rootstocks. The second purpose considers the feasibility of altering existing top-root relationships of susceptible orchard trees. Such alterations include topworking (substituting a tolerant top), inarching (substituting a tolerant root), and bridgegrafting (substituting a tolerant intermediate between top and root).

Rootstock Trials

The rootstock investigations were undertaken in 1945 at a time when only sweet orange tops on sour orange roots were known to be susceptible to quick decline. Reports from other countries had indicated that other susceptible combinations would be found. Two sets of experiments were begun at that time.

Rootstock Trials Planted 1945 and 1946. For these experiments, 620 trees of various top-root combinations were obtained from commercial nurseries or from nurseries of the Citrus Experiment Station. They were planted as replants in the orchards of nine coöperators in the quick-decline area of the Azusa-Covina district (Los Angeles County). Trees on 10 rootstock were included. All of these trees were exposed to natural infection by quick decline. However, the trees in one orchard were also inoculated, in the spring of 1947, with buds from diseased trees, in a manner described by Wallace and Fawcett (*20*).

The Baldwin Park and Associated Plantings. In the spring of 1945, seeds of 125 types of citrus and citrus relatives were gathered from the variety orchards at the University of California Citrus Experiment Station, Riverside, from similar orchards at the University of California at Los Angeles, or from other sources.[3]

The seeds were germinated in deep flats in a greenhouse at Riverside. About 35 of the resulting seedlings of each variety were transplanted to a nursery in Corona in the fall of 1945. Both Riverside and Corona were free of known cases of quick

[3] Seeds were furnished by E. Mortensen, University of Texas Agricultural Experiment Station, Winter Haven, Texas; F. E. Gardner, U. S. Department of Agriculture, Orlando, Florida; and by commercial growers.

decline until 1949. The various seedlings were budded with a uniform strain of Valencia sweet orange in the spring of 1947. In addition, 35 seedlings each of sweet orange, sour orange, and Rough lemon were double-worked to all possible combinations of those three species.

About 3,500 trees were balled from this nursery in May of 1948 and planted in the following manner: 2,112 trees of Valencia on 125 different rootstocks were placed at Baldwin Park in June, 1948. In addition, there were 93 of the double-worked trees mentioned above. Each combination was planted in single-row plots of 2, 4, or 6 trees each, in a randomized block experiment with four replications. One half of the trees (the odd-numbered in the rows) was inoculated in August, 1948. The other half (the even-numbered in the rows) was not inoculated. Each inoculated tree was budded high on the trunk with one bud from each of three diseased trees. Six trees were used as sources of inoculum, and buds from each source tree were used in two of the randomized blocks. The inoculation buds were held in place with strips of gummed tape. The "take" of these buds was poor, and the inoculation process was repeated in the same manner in October, 1948. Rubber budding strips were used for wraps. A good "take" was obtained in the second budding attempt. The inoculation technique of inserting three tissue grafts is considered to have resulted in the introduction of large quantities of inoculum. The check trees were not budded.

Twelve hundred trees from the Corona nursery were planted in the orchards of 10 coöperators, half of which were outside any known quick-decline area. None of these trees was inoculated, but those in the decline area were exposed to natural infection. Some plantings were on old citrus soil. These are expected to be long-term plantings, and it is hoped that they will furnish much of the information in regard to the horticultural value of those stocks shown to be tolerant to quick decline as a result of the inoculation trials. Results are not reported here.

Trees with other tops and roots were planted in 1949, 1950, 1951, and 1952. Still others are being grown and will be planted later.

Alteration of Top-Root Relationships of Orchard Trees in Topworking. Eighteen trees of Valencia sweet orange on sour orange root, showing varying stages of quick decline, were entirely or partly topworked in 1945, by means of cleft grafts, to Marsh seedless grapefruit at the E. B. Griffith orchard near Covina. Twenty-eight similar trees were partly or entirely topworked to Eureka lemons at the J. B. Stair grove in the Glendora area. Both orchards are in Los Angeles County. The grafts were inserted in the primary scaffold or in the secondary limbs of the trees. All sweet orange growth was subsequently removed.

Inarching. The substitution of tolerant roots for the susceptible roots of budded orchard trees was attempted by this procedure. Inarches were established in 1945 and 1946 in the groves of 10 coöperators in the Los Angeles County quick-decline area. A total of 255 Valencia trees on sour orange root, of different ages and in varying stages of quick decline, were inarched with either sweet orange or Rough lemon seedlings. Generally, four inarches were inserted per tree. Some four- and five-year-old trees received only two inarches per tree. The trees were not cut back at the time of inarching, but some of them, later on, were severely pruned and treated in other ways. Suckers were allowed to grow on the inarches for the first year in order to encourage inarch growth.

Additional unaffected trees, bordering on the quick-decline zone, were inarched in 1949. The trees are Valencia sweet orange on sour orange roots. Several species of citrus and citrus relatives were used for inarching. Results of the 1949 inarching are not yet available.

Bridgegrafting. Bridgegrafting over the bud union with grafts from a tolerant intermediate seedling was attempted on a small scale. In 1945 a total of 257 bridgegrafts was placed in 70 trees in orchards of seven coöperators. Rough lemon was used as the source of supply for the grafting wood. The number of bridgegrafts per tree varied with the size of the tree, some of the larger trees having six to eight. A high percentage of the bridgegrafts failed to become established.

RESULTS

Rootstock Experiments

1945–1946 Plantings. The appearance of quick-decline symptoms on trees of this series of experiments up to February, 1950, is shown in Table 1. Of the trees with sweet orange tops, those on bittersweet roots were first visibly affected by quick decline, and developed the most severe symptoms. Those on sour orange roots were next to show the effects

Table 1—Symptom Indications of Quick Decline in Various Top-root Combinations in Preliminary Rootstock Trials Planted 1945 and 1946 (Last observation, February, 1950)

No. of trees	Scion	Intermediate	Stock	Symptoms*
45	Sweet orange†	....	Bittersweet	+
67	Sweet orange†	....	Sour orange‡	+
39	Sweet orange†	....	Grapefruit	+
4	Sweet orange†	....	Pink shaddock	+
56	Sweet orange†	....	Sampson tangelo	..
52	Sweet orange§	....	Sweet orange	–
136	Sweet orange‖	....	Rough lemon	–
48	Sweet orange‖	....	Troyer citrange	–
34	Sweet orange‖	....	Morton citrange	–
39	Sweet orange†	....	King mandarin	–
7	Grapefruit¶	....	Sour orange	–
9	Lemon**	....	Troyer citrange	–
18	Lemon**	....	Morton citrange	–
6	Sweet orange†	Sour orange	Sweet orange	+
6	Grapefruit¶	Sour orange	Sweet orange	+
3	Grapefruit¶	Sweet orange	Sour orange	+
3	Grapefruit¶	Sweet orange	Bittersweet	+
6	Lemon**	Sour orange	Sweet orange	–
3	Lemon**	Sweet orange†	Sour orange	–
3	Lemon**	Sweet orange†	Bittersweet	–
3	Sour orange	Sweet orange	Sour orange	–
3	Sour orange	Sweet orange	Bittersweet	–
10	Sour orange	....	Sweet orange	–

* + = diseased; — = healthy.
† Valencia variety.
‡ Keen sour orange and unknown sour orange varieties.
§ Valencia, Bedmar, (Verna), and Viciedo varieties.
‖ Valencia and Washington Navel varieties.
¶ Marsh variety.
** Eureka and Lisbon varieties.

of the disease. While the bittersweet is considered a variety of sour orange, the two differ both morphologically (*58*) and chemically (*40*). Sweet orange trees on grapefruit roots have shown mild symptoms from time to time. As of 1952, however, no mature commercial trees of sweet orange on grapefruit roots show symptoms of quick decline, although some have been exposed to natural infection for 10 years. It is expected, however, that such trees will eventually be affected by the disease. In the 1945–1946 plantings, sweet orange trees on pink shaddock roots showed the first symptoms of decline in 1949.

In the 1945–1946 plantings, sweet orange tops on roots of sweet orange, Rough lemon, Troyer citrange, and on King mandarin did not show apparent symptoms. Certain of the artificially inoculated trees of some of these combinations are, however, showing evidence of the disease in the Baldwin Park experiments. The Morton citrange stocks budded to Valencia orange show severe stem pitting symptoms in 1952. The health and vigor of the top was not apparently affected at that time.

Two-year-old trees of grapefruit on sour orange roots inoculated with diseased buds in 1947 showed no leaf symptoms by 1950. These observations were not in accord with some later inoculations. The susceptibility of this combination is also indicated as a result of the topworking experiments discussed on page 28.

Lemon scions on Troyer and Morton citranges have been healthy in so far as quick decline is concerned. Lemon tops are known to be tolerant to quick decline, even on sour orange roots.

The experiments with the use of interstocks with various tops and roots indicate that the introduction of susceptible interstocks into otherwise satisfactory combinations has resulted in quick decline. Thus, trees of sweet orange/sour orange/sweet orange (fig. 2) were found to be susceptible. Likewise, grapefruit/sour orange/sweet orange, and grapefruit/sweet orange/sour orange trees have declined. Lemon tops, however,

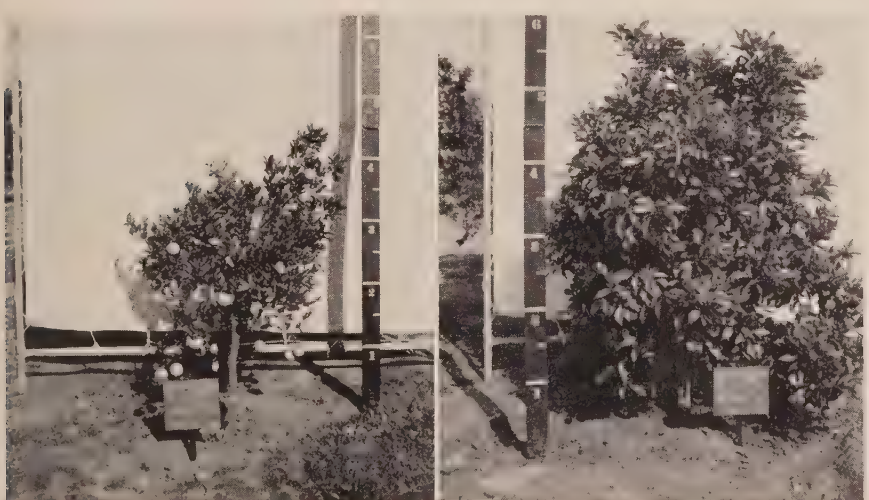

Fig. 2.—Left: five-year-old tree of sweet orange/sour orange/sweet orange, inoculated and showing symptoms of quick decline. Right: five-year-old tree of sour orange/sweet orange/sour orange, inoculated but healthy.

were healthy on these combinations of stocks and interstocks.

Sour orange tops were also found tolerant with sweet orange, sour orange, and bittersweet roots and interstocks (fig. 2). Sour orange seedlings in other trials grew satisfactorily.

The development of quick decline symptoms on the trees in the 1945–1946 plantings has been slow, and the symptoms have been mild. This may have resulted from the fact that many of the trees grew slowly, probably because they were frequently planted in orchards that were due for removal and had poor care. On such trees, symptom expression is initially less pronounced than on normally vigorous trees.

Baldwin Park Rootstock Experiment. There appear to be no genetic incompatibilities between the Valencia orange scion and the wide range of rootstock varieties in the 1948 plantings at Baldwin Park. The growth of the noninoculated trees was very satisfactory. The present indications as to the tolerance of the various combinations to quick decline are in many instances tentative. In many cases several of the inoculated trees in certain top-root combinations are now showing symptoms of quick decline, while other similar trees are still healthy. Although a few of the noninoculated trees have more recently developed symptoms as a result of natural infection, not enough are affected to permit conclusions to be drawn from these trees alone.

The first effects of the inoculations made in 1948 were evident during the following winter. Forty-three of the inoculated trees suffered frost injury to the tops and trunks, as compared with 14 of the check trees. Combinations on lemon, lime, and shaddock stocks were the more tender.

In July, 1949, the first symptoms of quick decline appeared on a few combinations, but they were not well defined. Additional combinations continued to express symptoms through the summer, and the severity of symptoms increased. In regard to the time of symptom appearance and the rate of symptom progression, it was evident that the inoculated trees on some rootstocks are much more affected by artificial inoculations with quick decline than are others.

On November 11–12, 1949, and also at subsequent dates, all of the trees were graded. The standards used are as follows: grade 0 = healthy; grade 0.5 = suggestive of the first stages of quick decline —reduced growth, small leaves, slightly off-color, off-bloom; grade 1 = definite quick decline—marked stunting, open growth, off-color, small leaves, slight vein clearing, off-bloom; grade 2 = marked stunting—yellowing of leaves, vein clearing, slight defoliation, off-bloom, fruit set, wilting; grade 3 = marked yellowing of the leaves, vein clearing, medium defoliation, excessive bloom or off-bloom, fruit set, wilting; and grade 4 = severe defoliation—excessive bloom or off-bloom, fruit set, no growth, tree nearly dead or dead. Not all of these symptoms are required in each case for grading.

Individual trees showing advanced decline symptoms were re-examined to determine if the observed symptoms were due to gummosis, dryness of soil, gopher injury, mechanical girdling, a variant rootstock, or other causes than quick decline. When such evidence was found, the records of those trees were not used. Trees showing symptoms of grade 1 are probably definitely not tolerant to quick decline, but combinations are listed as susceptible only when at least three trees showed grades of 0.5 or higher and the growth of the inoculated trees was considerably reduced. Classification is designated as uncertain only if one or two of the inoculated trees of a combination were showing symptoms of grade 0.5, or if symptoms and tree growth measurements did not substantiate one another. Combinations are designated therefore as tolerant, susceptible, or uncertain. All frost-damaged trees were excluded.

The grading of May 5–6, 1950, was made during the flowering period. The presence of prolific flowering on young trees serves as an excellent symptom of the disease. The last grading reported herein was made on August 1–2, 1950. Results of this grading are presented in Table 2. This table also presents a summary of the rate of growth of the inoculated trees, relative to the growth of noninoculated trees, between August, 1948, and August, 1950. Measurements of the diameter of the scion were taken 4 inches above the bud union.

In November, 1949, 12.45 per cent of the inoculated trees showed symptoms of quick decline, but only 0.19 per cent of the noninoculated trees. The small number of noninoculated trees that developed symptoms during the first year may be partly attributed to low insect populations in the trial plots. By May, 1950, 27.37 per cent of the inoculated trees was affected, and 5.88 per cent of the check trees. The August, 1950, inspection revealed 41.60 per cent of the inoculated trees to be affected, and 10.12 per cent of the trees that were not artificially inoculated.

Trees on some roots, such as sour orange or shaddock, appeared to be much more affected by natural infection than others, such as trees on roots of the mandarin hybrids or trifoliate orange hybrids. Differences in tolerance to natural and to artificial infection have also been observed by Costa, Grant, and Moreira (*13*).

The data in Table 2 also show that the majority of the artificially inoculated trees has made less growth than those that were not inoculated by budding. In the case of some stocks, this has been the only observed effect of inoculation. This was noticeable with trees on sweet orange roots, on some of the mandarin roots, and on the roots of some of the trifoliate hybrids. In only a very few cases did the inoculated trees make greater growth than those which were not inoculated, and in these cases the increase is considered so small as to be within the realm of experimental error. The significance of the effects of inoculation on the growth of trees that developed no other symptoms of quick decline has not been entirely established; it is not believed to be due to mechanical effects. The possibility exists that some other virus, such as psorosis, which is known to reduce tree growth, was also introduced with the buds that were used for inoculation. The reduction in growth has been more severe during the second year than it was the first year following inoculations.

Sour Oranges. Nineteen varieties of sour orange were used as rootstocks in these trials. Some trees of all of these combinations showed symptoms by November, 1949. By August, 1950, a greater number of trees were affected, and the degree of symptom expression was more advanced. In these combinations it was interesting to follow the rate of symptom development in the inoculated trees and in the check trees infected by the vector. In November, 1949, 36.8 per cent of the inoculated trees showed symptoms, and only 1.1 per cent of the noninoculated trees. By May, 1950, the percentage of visibly affected trees was 60.3 for the inoculated and 10.9 for the noninoculated. In August, 1950, the number of trees showing symptoms had increased to 70.7 per cent for the inoculated trees and 20.7 per cent for the noninoculated.

Trees on certain varieties of roots appeared to show symptoms sooner than did those on some other varieties (see table 2). The average growth of the inoculated trees of each combination was less than that of the noninoculated. Workers in Brazil (*25, 27*) also found sweet oranges to be susceptible on all the varieties of sour orange that they have tested as rootstocks. The possibility that a variety of sour orange may be found which is tolerant to quick decline seems highly improbable.

(Continued on page 24)

Table 2—Response of Valencia Orange Trees on Various Rootstocks to Inoculation and Natural Infection with Quick Decline Virus

(Baldwin Park, California, 1950)

Rootstock	Inoculated trees: Total number	Inoculated trees: No. affected and degree of symptom* 0.5	Inoculated trees: No. affected and degree of symptom* 1–4	Noninoculated trees: Total number	Noninoculated trees: No. affected and degree of symptom* 0.5	Noninoculated trees: No. affected and degree of symptom* 1–4	Relative growth of inoculated trees (per cent) †	Indications of suscepti-bility ‡
Sour Orange								
Citrus taiwanica (Nansho daidai)	7	3	1	6	0	0	−17.1	S
Rancho Sespe	12	2	5	10	0	1	−11.8	S
Bittersweet (Stow 15)	11	2	7	11	0	0	−21.4	S
Daidai double calyx	9	3	5	9	0	1	−30.3	S
Brazilian	12	2	7	12	2	0	−27.0	S
Standard	12	1	7	12	1	0	−22.9	S
Sweet-sour (Stow 20)	8	1	5	10	1	0	−25.7	S
Bergamia	10	0	8	10	1	0	−37.5	S
Oklawaha	9	1	6	9	3	2	−29.4	S
Sauvage	10	2	5	10	4	0	−23.1	S
China	12	2	5	12	1	1	−28.6	S
Olivelands (Fawcett 363)	12	2	9	12	2	1	−35.5	S
Palermo (FPI 85726. Fawcett 43)	12	6	2	12	2	2	−14.2	S
Seville (FPI 84564)	3	1	2	3	0	0	−36.8	S
Keen	5	0	3	6	2	0	−29.7	S
Dummitt (Webber-Fawcett 15)	4	1	3	4	2	0	−24.2	S
Tunis (FPI 85727. Fawcett 44)	2	0	2	1	0	0	−35.7	S
Paraguay	7	0	6	7	2	1	−25.0	S
Dummitt bittersweet (Webber-Fawcett 4)	6	1	4	6	2	0	−16.7	S

Sweet Orange								
Blackman (UCLA)	10	0	0	11	0	0	−13.2	U
Blackman (UCLA)	11	0	0	11	0	0	−5.4	T
Trovita (Frost 12)	9	0	0	9	0	0	−13.5	U
Trovita (Frost 12)	9	0	0	9	0	0	−6.4	T
Rufert (Ruvel. Frost 14)	9	0	0	8	0	0	−18.6	U
Koethen	9	0	0	8	0	0	−5.9	T
Dolandam (CPB 7829)	11	2	1	12	1	1	−13.9	S
Bessie seedling	9	0	2	9	1	0	−15.4	S
Lima Orange (Brazil)	7	1	0	6	0	0	−22.2	U
Corona	11	0	1	11	0	0	− 2.9	U
Bidwells Bar	9	0	0	9	0	0	0.0	T
Camulos Ranch	10	1	0	11	0	0	−5.4	U
Madam Vinous seedling	8	1	0	9	0	0	−13.6	U
Bessie	7	0	0	7	0	0	+2.8	T
Valencia (Nucellar seedling)	7	1	0	7	0	0	−12.5	U
Koethen	9	2	0	9	0	0	−18.4	U
Total or average	145	8	4	146	2	1	−10.3	
Shaddock								
Shaddock (FPI 102460 a)	8	4	1	10	0	0	−5.7	S
Kao-Panne (CPB 10078)	8	2	4	9	5	1	−31.2	S
Citrus decumana	11	6	4	10	2	0	−28.1	S
Chinese pummelo	11	1	4	11	0	0	−6.7	S
Alamoen seedling (FPI 97930)	10	3	4	10	1	1	−25.7	S
Pink (CPB 10305)	10	2	5	10	2	3	−22.6	S
Alamoen (Florida)	6	1	3	6	0	0	−10.3	S
Pink (CPB 10312)	8	3	3	9	1	0	−20.6	S
Citrus celibica, var. Southwickii (CPB 10125)	8	3	5	8	1	0	−32.5	S
Total or average	80	25	33	83	12	5	−20.4	

(See end of table for footnotes)

Table 2—Response of Valencia Orange Trees on Various Rootstocks to Inoculation and Natural Infection with Quick Decline Virus—(*Continued*)

Rootstock	Inoculated trees: Total number	Inoculated trees: No. affected and degree of symptom* 0.5	Inoculated trees: No. affected and degree of symptom* 1–4	Noninoculated trees: Total number	Noninoculated trees: No. affected and degree of symptom* 0.5	Noninoculated trees: No. affected and degree of symptom* 1–4	Relative growth of inoculated trees (per cent)†	Indications of suscepti-bility‡
Shaddock Hybrid								
Pummelo × sweet orange (China)	10	1	6	11	2	0	−34.3	S
Shaddock × St. Michael sweet orange (CES 42–1)	10	2	7	10	3	2	−25.8	S
Shaddock × St. Michael sweet orange (CES 42–2)	10	1	9	10	1	2	−46.7	S
Total or average	30	4	22	31	6	4	−35.6	
Grapefruit								
Griffith Ranch (Covina)	6	1	0	6	0	0	−5.1	U
Blackman	10	4	1	9	2	0	−5.3	S
Poorman's orange (CPB 10252)	7	1	3	7	0	2	−16.7	S
Hall Silver (Selfed nucellar)	11	5	2	11	0	0	−13.5	S
CES 1215 (UCLA)	8	3	2	8	1	0	−8.8	S
Seedling (CES 343. Florida)	7	4	0	7	0	0	−18.9	U
Royal (Nucellar)	8	2	0	8	0	0	−20.6	U
Camulos Ranch (Piru)	6	4	0	6	0	0	−17.9	U
Seedling (CES 343. Florida)	6	0	0	5	0	1	0.0	U
Total or average	69	24	8	67	3	3	−11.9	

Lime								
Red (Santa Barbara)	9	0	0	10	0	0	−4.8	T
Red (Philippines CPB 10557)	7	0	0	9	1	0	+9.5	T
West Indian	10	0	0	9	0	0	−2.3	T
Kusaie	9	2	0	9	0	1	−12.5	U
Palestine Sweet	12	5	1	12	0	0	−14.3	S
Borneo (CPB 11845)	11	2	0	11	0	0	−18.2	U
Total or average	58	9	1	60	1	1	−7.1	
Lemon								
Rough lemon (Limoneira Ranch)	11	0	0	11	0	1	+2.1	T
Variant	8	2	1	9	0	0	−13.3	S
South African Rough lemon (CPB 10207)	9	2	0	9	0	0	−11.1	U
Lemelo (CPB 11045)	7	2	5	9	5	2	−20.0	S
Khoubs el Arsa, Citrus de Borneo (Morocco)	10	1	7	11	2	0	−38.6	S
Khoubs el Arsa (Morocco. FPI 91449)	11	1	9	11	0	0	−40.9	S
Rough lemon (Florida)	8	0	1	9	0	0	−4.8	T
India (FPI 10247)	11	0	0	11	0	0	−6.8	T
FPI 103496	10	4	0	10	0	0	0.0	U
Rabat (Morocco)	11	3	7	11	3	0	−8.8	S
Eureka (Fawcett 85)	8	2	2	8	0	0	−20.9	S
Lisbon	2	0	1	3	0	0	−20.4	U
Sweet (Brazil)	3	1	1	3	0	0	−5.0	U
Total or average	109	18	34	115	10	3	−14.5	

Table 2—Response of Valencia Orange Trees on Various Rootstocks to Inoculation and Natural Infection with Quick Decline Virus—(*Continued*)

Rootstock	Inoculated trees: Total number	Inoculated trees: No. affected and degree of symptom* 0.5	Inoculated trees: No. affected and degree of symptom* 1–4	Noninoculated trees: Total number	Noninoculated trees: No. affected and degree of symptom* 0.5	Noninoculated trees: No. affected and degree of symptom* 1–4	Relative growth of inoculated trees (per cent)†	Indications of susceptibility‡
Mandarin								
Kinokuni (China)	11	3	2	11	0	2	−11.1	S
Dancy	9	1	1	9	1	0	−14.7	U
Ponkan	8	1	0	8	0	0	−13.2	U
Cleopatra seedling 462	9	2	0	9	0	0	−5.6	U
Willow Leaf	6	6	0	6	0	0	−7.9	U
Total or average	43	13	3	43	1	2	−10.5	
Mandarin Hybrid								
Kinnow mandarin (King × Willow Leaf. S1–C–5–3)	8	1	0	8	0	0	−8.3	U
Mandarin (King × Willow Leaf. S1–C–3–7)	4	0	1	6	0	0	−35.7	U
Thornton tangelo (CPB 11399)	7	3	1	8	0	0	−7.9	S
Thornton tangelo (CPB 1282 H-G 28)	9	3	1	8	0	0	−17.9	S
San Jacinto tangelo (CPB 1213–B)	4	0	0	4	0	0	−2.7	T
Tangelo (Marsh grapefruit × Dancy tangerine)	7	0	1	9	0	0	−22.5	U
Tangor (Owari Satsuma × Valencia orange)	10	3	3	10	2	1	−8.9	S

Minneola tangelo	8	4	1	8	0	1	−23.1	S
Minneola tangelo	6	1	0	6	0	0	−9.5	U
Tangelo (Willow Leaf × Imperial grapefruit)	9	2	1	9	0	0	0.0	U
Tangor (Willow Leaf × Valencia orange. 2–64–65)	8	0	0	9	0	0	−5.6	T
Tangor (Willow Leaf × Valencia orange. 2–64–101)	6	1	0	6	0	0	−15.8	U
Owari tangelo (Satsuma × Imperial grapefruit)	9	4	1	9	2	0	−19.4	S
Kara (Satsuma × King tangor)	5	0	0	6	0	0	−12.8	U
Tangor (Willow Leaf × Blood orange)	4	0	0	4	0	0	0.0	T
Orlando (Lake) tangelo	9	1	0	9	0	0	−16.7	U
Sampson tangelo	9	1	1	9	0	0	−14.3	U
Mency tangor (Sweet orange × Dancy tangerine)	8	3	0	9	0	0	−19.0	U
Sexton tangelo (Webber-Fawcett 7)	4	2	1	4	0	0	−30.0	S
Seminole tangelo (CPB 52018)	2	1	0	2	0	0	−16.7	U
Total or average	136	30	12	143	4	2	−14.3	
Trifoliate Orange								
Large flowered	4	0	0	4	0	0	−10.5	U
Tetraploid	8	2	2	8	0	2	−2.9	U
Texas Station 16471	9	0	1	9	0	0	−11.1	U
CES 1717	9	1	0	9	0	0	−5.9	U
Webber-Fawcett 22	5	0	0	5	1	0	0.0	T
CPB 11461	7	1	0	7	1	0	−11.8	U
Rubidoux	6	0	0	6	0	2	+13.3	T
Pomeroy	4	0	0	4	0	0	+3.1	T
Total or average	52	4	3	52	2	4	−7.3	

Table 2—Response of Valencia Orange Trees on Various Rootstocks to Inoculation and Natural Infection with Quick Decline Virus—(*Continued*)

Rootstock	Inoculated trees			Noninoculated trees			Relative growth of inoculated trees (per cent)†	Indications of suscepti-bility‡
	Total number	No. affected and degree of symptom*		Total number	No. affected and degree of symptom*			
		0.5	1–4		0.5	1–4		
Trifoliate Orange Hybrid								
Citremon (CPB 46219A)	7	3	2	8	0	0	−13.9	S
Etonia citrange	4	0	1	4	0	0	−19.4	U
Troyer citrange	9	3	1	9	0	0	−9.8	U
Thomasville citrangequat (CPB 48010)	9	3	0	9	0	0	−23.1	U
Sacaton citrumelo (CPB 45546)	7	2	0	7	0	0	+5.7	U
Carrizo citrange (CPB 45019–B)	10	2	0	10	0	0	−11.4	U
Morton citrange	9	3	2	9	0	0	−7.1	U
Total or average	55	16	6	56	0	0	−11.3	
Ichangensis Hybrid								
Ichangensis (China. SPI 46128)	6	3	0	6	0	0	−11.1	U
Ichangensis (China. CES 1215)	6	0	0	7	0	0	0.0	T
Kansu orange (Yuzu. CPB 11298)	5	1	0	6	1	0	0.0	U
Yuzu orange (Japan)	7	2	2	7	1	0	−13.3	U
Ichang pummelo (CPB 10500–W)	7	1	1	8	0	0	−18.7	S
Ichang lemon (CPB 10122)	7	1	2	7	1	1	−23.5	S
Total or average	38	8	5	41	3	1	−11.1	

Miscellaneous								
Diamante citron (C. medica)	9	1	0	11	0	0	−10.5	U
Citrus macroptera (Tahiti)	10	2	2	10	1	0	−23.1	S
Bigaraldin (Bigardier sour orange × Calamondin)	9	4	2	9	1	0	−22.7	S
Citrus moi (CPB 10123)	6	0	0	8	0	0	+2.4	T
Total or average	34	7	4	38	2	0	−10.8	
Grand totals	1,012	197	229	1,037	70	35	......	..

* All trees were graded in August, 1950. Standards used are as follows: Grade 0 is healthy. Grade 0.5 is suggestive of the first stages of quick decline—reduced growth, small leaves, slightly off-color, off-bloom. Grade 1 signifies definite early symptoms of quick decline—marked stunting, open growth, off-color, small leaves, slight vein clearing, off-bloom. Grade 2 shows marked stunting, yellowing of leaves, vein clearing, slight defoliation, off-bloom, fruit set, wilting. Grade 3 indicates marked yellowing of leaves, vein clearing, medium defoliation, excessive bloom or off-bloom, fruit set, wilting. Grade 4 shows severe defoliation, excessive bloom or off-bloom, fruit set, no growth, tree nearly dead or dead. All symptoms are not required in each case, for classification.

† Average percentage increase (+) or decrease (−) in growth of inoculated trees, as compared with noninoculated trees, as indicated by changes in diameter of trunk 4 inches above bud union from August, 1948, to August, 1950.

‡ Tentative classification. T = tolerant; S = susceptible; U = uncertain.

Sweet Oranges. The growth of trees on 14 of the 16 varieties of sweet orange stocks was reduced on the inoculated trees. Since this species has been assumed to be tolerant when used as a stock, the reduction of the growth of the young trees may be the result of the inoculation technique used. Inoculated trees (with the exception of those on a selection of the Bessie variety) develop mild symptoms similar to those of quick decline. The results obtained with this Bessie selection are not typical of the other sweet oranges since the symptoms are more severe and may be the result of an error in identity which is yet to be confirmed. However, the condition of the inoculated trees on sweet root has not improved as of August, 1952, and the stunting effect is accompanied by yellowing and small leaves.

Shaddocks. The shaddocks, when used as stocks for Valencia orange, were very susceptible to quick decline. The nine shaddocks tested appeared to be equally susceptible and showed symptoms about as rapidly and to the same degree as trees on sour orange roots. In all cases the inoculated trees made less growth than did the noninoculated. The results agree with observations made on root stock trials at Campinas, Brazil (*25, 27*).

Shaddock Hybrids. The three shaddock hybrid stocks developed symptoms earlier and to a more severe degree than did the average of the sour orange stocks. These symptoms were characterized by greater yellowing of the leaves, leaf vein clearing, and heavy off-season flowering and setting of fruit. Evidence of the high susceptibility of these hybrids was substantiated by the growth measurements. The reduction in growth of the inoculated trees, as compared with the noninoculated trees, was greater than the average of any other group of combinations. It appears that the degree of susceptibility is not lessened in these shaddock hybrids nor in other hybrids by nature of one of the parents being resistant.

Grapefruit. Many of the inoculated trees on grapefruit stocks are now showing symptoms of quick decline and reduction in growth. These effects are sufficiently severe on four stocks to warrant their being classified as susceptible. The reaction of the others is classed as uncertain at this time. The results are in agreement with the observations of workers in Brazil (*25, 27*). The effects of natural infection are not, however, in agreement with the lack of symptoms observed on old orchard trees in the quick-decline area.

Limes. Valencias budded on acid or mandarin-type lime stocks appear to be tolerant to quick decline two years after mass inoculation. Inoculated trees were markedly stunted only on the Kusaie, Borneo, and Palestine Sweet varieties. The negative results to date, with the acid limes (West Indian), are not in agreement with the observations of Grant *et al.* (*25, 27*) on tristeza. The mandarin limes (Rangpur) were found tolerant as stocks in Brazil. Trees on Palestine Sweet lime appear to be susceptible to quick decline in the present trials.

Lemons and Lemon Hybrids. Among the lemons, lemon hybrids, and several lemon-like selections grouped for convenience with that species, only three out of 13 varieties appeared to be tolerant when used as stocks for the Valencia. These are two standard varieties of Rough lemon, and a Rough lemon type from India. All other varieties of lemon stocks are classed as susceptible or uncertain. The Lisbon and Brazilian sweet lemon stocks are classified as uncertain at this time because of the small number of trees involved. Symptoms were very pronounced on some of the lemon and lemon-like stocks. Two selections of Khoubs el Arsa and the Rabat (possibly lemon x sour orange) appeared to be even more susceptible than trees on sour orange stock.

Mandarins. The mandarins as a group must at present be listed as uncer-

tain in respect to their tolerance to inoculation with quick decline. Sixteen of 43 inoculated trees have developed mild symptoms of the disease. The affected trees on mandarin roots were characterized by small leaves and thin foliage. The inoculated trees were, in general, smaller than the noninoculated trees, which generally appeared healthy at the last grading. The Kinokuni and Willow Leaf varieties are suspected particularly. The results with inoculated trees do not coincide with observations made in Brazil, where all the mandarins tested as stocks have remained tolerant (*25, 27*). Terra suspects that the Batanges mandarin is mildly susceptible as a stock in Java (personal communication, dated May 2, 1950).

Mandarin Hybrids. Some of the mandarin hybrids appeared to be tolerant as stocks, while others appeared to be susceptible. Of 136 inoculated trees, 42 showed symptoms of quick decline by August, 1950. In May, 1950, only 13 of the inoculated trees showed symptoms. The time necessary for satisfactory symptom expression was longer with mandarin hybrids than with trees on sour orange stock, and symptom expression was milder. Trees on nearly all of the mandarin hybrid varieties were stunted. However, the inoculated trees on San Jacinto tangelo, and two tangors (Willow Leaf x Valencia 2-64-65 and Willow Leaf x Blood orange) were not appreciably reduced in growth and developed no symptoms. The trees on Kara showed no symptoms other than moderate stunting. Two selections on Thornton tangelo appeared to be susceptible, as were a tangor (Owari Satsuma x Valencia), a selection of Minneola tangelo, the Owari tangelo, and the Sexton tangelo. All other combinations must be designated as uncertain in the present classification. Of the tangelo varieties under test as stocks in the present plots, Thornton was the only one that was also found to be susceptible in Brazil (*25, 27*).

Trifoliate Oranges. Results with trifoliate oranges as stocks are uncertain as of 1950. Symptoms (generally mild) resembling quick decline were present on a few trees of most varieties. Almost as many noninoculated trees were affected by 1950 as were inoculated trees. This suggests that some factor other than quick decline must be considered. The inoculated trees on most trifoliate stocks were stunted. Some differences among varieties were apparent. A tetraploid trifoliate has shown symptoms that are the most typical of quick decline. It is interesting to note that a large-flowered trifoliate, similar to that tested by Grant *et al.* (*25, 27*) and found to be tolerant to tristeza, has developed no symptoms of quick decline at Baldwin Park.

Trifoliate Orange Hybrids. Among these hybrids, a citremon appeared most susceptible as of August, 1950. Classification of the others must be considered as uncertain at this time since some trees in all combinations, except a citrumelo, show varying degrees of stunting, and also symptom expression, such as small leaves and thin foliage. Of the 55 inoculated trees on hybrid roots, 22 showed symptoms of sufficient degree to justify quick decline grades, while all of the noninoculated trees appeared healthy. These observations do not agree with those made in Brazil (*25, 27*) where various trifoliate hybrids, except the citremon, appeared to be tolerant as stocks.

Ichang Hybrids. Varieties SPI 46128 and CES 1215 are believed to be hybrids of *Citrus ichangensis*, while the Ichang pummelo and Ichang lemon are known hybrids. The Yuzu orange and the Kansu orange are apparently synonymous varieties, being hybrids of *Citrus ichangensis* and *Citrus reticulata*. Of the inoculated trees on these stocks, only those on CES 1215 appeared tolerant in 1950. Trees on the other stocks showed varying degrees of quick decline. Trees on the Ichang pummelo and Ichang lemon developed the more severe symptoms and

stunting, and are classed as susceptible. Those on SPI 46128, on Yuzu, and on Kansu may be classed as uncertain.

Miscellaneous Stocks. *Citrus moi* appeared to be the only stock in the miscellaneous grouping that was tolerant to quick decline. The inoculated trees were not stunted, and no symptoms were observed. Trees on *Citrus macroptera* were found to be susceptible as were those on the Bigaraldin, which is a hybrid of Bigardier sour orange x calamondin. The classification of the citron is as yet uncertain.

Comment on Results of Rootstock Trials

Additional time is needed for the observation of the trees in these rootstock experiments. In several cases, the indications of susceptibility at Baldwin Park and in the 1945–1946 plantings were the same when sweet orange was budded on similar roots, but there are interesting exceptions. Thus sweet orange trees on sour orange, bittersweet orange, grapefruit, and shaddock stocks have developed symptoms in both sets of trials although the rate of development was much slower in the 1945–1946 plantings. On the other hand, the growth of similar trees on Troyer or Morton citrange, on sweet orange, or on mandarin stocks was reduced in the Baldwin Park plots. Although stem pitting has shown up on Morton citrange in the 1945 plantings, it has not appeared in the Baldwin Park plantings.

It seems logical that the inoculation technique used in the latter experiment intensified the effects observed. The reduction of growth of some top-root combinations, such as sweet orange on sweet orange, which have developed no other obvious symptoms of quick decline, may be temporary, or not indicative of the magnitude of the effects of inoculating mature trees. On the other hand, symptoms will probably become more severe in trees on the more susceptible stocks. It has been shown by Bennett and Costa (*2*) that a higher proportion of seedlings or young budlings develops tristeza when large numbers of the vector are used for inoculation. Costa, Grant, and Moreira (*13*) were able to cause the development of symptoms by inoculation of young sweet orange and sour orange seedlings, but they found that the condition of such seedlings later improved. Their tristeza inoculations resulted in more severe symptoms when made in the summer. Thus the initial reduction in rate of growth of certain top-root combinations resulting from the inoculation technique used in the summertime in the Baldwin Park plots may have exaggerated the effects of the inoculation, and the symptoms may not be permanent. That some combinations have not been stunted by the inoculation may be considered further evidence of variations in the tolerance of young sweet orange trees on various stocks to the disease.

Altering Top-root Relationships

Topworking. The trees that were completely topworked to lemons in 1945 have made normal growth. The size and color of the leaves and general appearance of the new tops were healthy, and their vigor was entirely satisfactory (color plate, p. 27). At the end of five years, many of these trees were yielding four to six boxes of fruit—satisfactory crops for trees of this size.

Recovery of trees that were only partially topworked to lemons was not satisfactory, however. The presence of the diseased sweet orange top on a part of the tree greatly inhibited the growth of the lemon scions on the other part. The presence of one diseased sweet orange limb on the tree was sufficient to affect the vigor and condition of the entire top. Growth flushes of the lemon shoots were short, leaves were small and light yellow-green in color. In several instances, trees that were partially topworked to lemons collapsed and died. One partially top-

Plate 1.—Above: Valencia on sour orange root three years after being partly topworked to lemon. Sweet orange top has collapsed, and lemon scions in the center are defoliated. Upon removal of the sweet orange limbs, the lemon scions have recovered and are making healthy growth. Below: lemon top five years after being topworked on Valencia on sour orange stock. Note healthy, vigorous growth of lemon scion although tree was probably infected with quick decline at time of topworking.

worked tree was observed while the entire top was in a stage of complete wilt (page 27). The sweet orange limbs were immediately removed, and in a few weeks normal new growth developed in the lemon scions. In the absence of the sweet orange top, the tree is now developing into a normal, healthy lemon tree. The practice of topworking susceptible trees to lemons, while entirely feasible, is not expected to be extensively used because of the economic aspects involved, and because many orange growing areas are not adapted to lemon growing. In specific cases there are frequently other objections.

Valencia orange trees, when either partially or completely topworked to grapefruit, made unsatisfactory growth and developed symptoms very similar to those of affected orange trees (fig. 3). The growth flushes were short; the leaves were small and chlorotic or bronzed. Flowering was heavy and tended to be off season. Fruit set was heavy, and the fruit grew in clusters. The fruit was very small and of very poor quality. The topworked trees failed to establish any strong shoots, and the tops were thus very bushy in appearance. Several of the partially topworked trees collapsed. In no instance did the growth of the topworked trees approach the growth of a healthy tree normally topworked to grapefruit outside the quick-decline area.

The results obtained with grapefruit tops are of interest, but it is difficult to explain why the trees topworked or double-worked to grapefruit showed symptoms of the disease, whereas trees of grapefruit on sour root the same age as the topworked replants did not show symptoms during the time of these observations. There are also old grapefruit trees on sour root, in the quick-decline area, which have been exposed to natural infection for five to 10 years without the development of symptoms of quick de-

Fig. 3.—Left: an infected Valencia on sour orange five years after being partly topworked to grapefruit. Note evident decline of sweet orange top and poor growth of grapefruit scion. Right: grapefruit top five years after being topworked on an infected Valencia on sour orange root. Top volume is small, there are no vigorous shoots, leaves are chlorotic, and there is a heavy crop set.

cline. Bitancourt (5) has shown that symptoms of tristeza are milder and later in appearing on grapefruit tops than on sweet tops. Perhaps topworking or double-working has accelerated disease expression because of food reserves expended in the process.

Results with the topworking of orchard trees were partially substantiated by results obtained with young, double-worked trees which served as replants in 1945. Inoculated lemon/sour orange/sweet orange trees remained healthy, as did the trees of lemon/sweet orange/sour orange, and lemon/sweet orange/bittersweet. However, trees of grapefruit/sweet orange/sour orange, and grapefruit/sweet orange/bittersweet consistently developed symptoms of the disease. Sweet orange/sour orange/bittersweet trees also developed symptoms, but trees of sour orange/sweet orange/sour orange, and of sour orange/sweet orange/bittersweet remained healthy.

In the more recent experiment at Baldwin Park, double-worked trees with various combinations of sweet orange, sour orange, and Rough lemon as top, root, and intermediate have shown symptoms only when the top is sweet orange and the root or intermediate is sour orange. In older orchards, Valencias on sour stock with a lemon intermediate have been observed to succumb to the disease. These results agree with the observations of Toxopeus (55) that a tolerant, compatible intermediate neither prevents nor delays decline.

Inarching. The insertion of sweet orange or Rough lemon inarches into the trunk above the bud union of trees in various stages of quick decline, or just before the appearance of symptoms, did not prevent the progress of the disease during the next two years, and many of the trees were removed. The trees had not been pruned at the time of inarching in 1945, and by 1947 it was evident that severe pruning would be needed to preserve the remaining ones. In the summer

Fig. 4.—Left: Valencia on sour orange five years after inarching, showing degree of recovery obtained. Right: five-year-old replant on a tolerant rootstock. Compare top volume with that of inarched tree.

of that year, therefore, the inarched trees were paired on the basis of symptom expression, and one tree of each pair was severely pruned. Some response to the inarching was thereafter observed in many trees, but the pruned trees have made considerably more improvement than the nonpruned ones. The improvement has been slow, however, and none of the trees has made a desirable recovery. In general, the tops of inarched trees are no larger after five years than are the tops of young trees that were planted on tolerant roots at the time the older trees were inarched (fig. 4).

The improvement of the inarched trees generally has been proportional to the relative growth of the inarch seedlings. Rough lemon inarches made more rapid growth than sweet orange inarches, and therefore had more beneficial effects. The average diameter of the Rough lemon inarches, measured about 3 inches above the soil line, was about 60 per cent greater in 1950 than was that of the sweet orange inarches. Although this indicates that the use of Rough lemon for inarching purposes is preferable to use of sweet orange, trees on the former rootstock have some undesirable qualities, especially in regard to the yields at advanced ages and the quality of the fruit which they produce.

The severity of the symptoms of quick decline at the time of inarching was observed to affect the growth of the inarches. This may be illustrated by data of the air-dry weights of below-ground portions of inarches obtained from one orchard in which all the trees were pulled up in 1948. The results, presented in Table 3, show that the largest inarches were obtained on grade 2 trees which had fair tops but poor root systems. The poorest growth was obtained with healthy or nearly healthy trees. In these cases, inarches apparently could not compete satisfactorily with the more normal root system of the trees. Poor inarch growth was also obtained when the trees were in advanced stages of quick decline (grades 3 and 4). In these cases, both the tops and the roots of the trees were in poor condition, and the trees were deficient in carbohydrates. These observations have been verified by measurements of the diameter of the stems of inarches of trees in varying stages of quick decline in several orchards.

Table 3—Relative Growth of Sweet Orange and Rough Lemon Inarches after Three Years on Trees in Various Stages of Quick Decline
(Inarch seedlings inserted 1945)

Quick decline grade*	Sweet orange inarches		Rough lemon inarches	
	Number of inarches	Average dry weight	Number of inarches	Average dry weight
		grams		grams
0	..	.....	4	53.5
0.5	6	56.7	..	.....
1	..	.....	..	.....
2	19	203.1	20	303.9
3	16	185.9	19	150.0
4	4	131.0	4	90.8

* In increasing order of severity of symptoms at time trees were removed.

Heavy pruning of the inarched trees in 1947 was observed to increase slightly the growth of the inarches. Thus, measurements 3 inches above the ground level, in 1950, showed that the average diameter of sweet orange and Rough lemon inarches of unpruned trees was 30.1 mm., and of pruned trees, 32.7 mm.

In 1947, some of the trees that had been inarched in 1945 were completely or partially girdled near the bud union in various ways in attempts to increase the growth of the inarches. In some cases, a strip of the sour orange bark 2 inches wide was removed below the bud union. In another treatment, the bark and also the wood, to a depth of ½ inch, were removed in the same way. In other cases, a V-shaped notch was cut from the bark under the inarches. The lines of this notch were about 2 cm. wide, and the exposed wood was scraped several times to prevent the regeneration of the cambium. In still another treatment, an inverted "funnel" (fig. 5) was similarly cut in the bark between (but not under) the inarches. Suitable control trees and inarches were available for comparison. These girdling practices were used in an effort to reduce the effects (if any) on the inarches of any toxic material (*15*) arising in the sour orange root system, and to direct the flow of nutrients to the inarches. All of them resulted in small, consistent increases in the growth of the Rough lemon and sweet orange inarches on both pruned and nonpruned trees. The average diameters of the sweet orange inarches treated in the various ways in the spring of 1950 were: control—27.2 mm.; bark girdled—30.4 mm.; bark and wood girdled—33.6 mm.; V-shaped notch—29.6 mm.; inverted "funnel"—33.6 mm. Of these practices, the deep, wide girdle extending into the wood of the sour orange trunk below the bud union, and the inverted "funnel" between the inarches appeared to have caused the greatest growth response.

Fig. 5.—Inarched tree, showing inverted "funnel" type of girdling procedure used.

Other treatments were also used. In one orchard the trunks of several small, affected trees of sweet orange on sour orange roots were completely severed below the bud union, and a piece of the trunk 2 inches wide was removed. The trees were mechanically supported. The results cannot be directly compared with those given in the previous paragraph since smaller inarches were inserted into these young trees. That the procedure increased inarch growth is indicated by 1950 measurements. These showed average diameters of 7.5 mm. for the inarches on control trees, and 12.0 mm. for those on trees from which the sour stock was severed. This practice is applicable only to small trees, and there was no indication that it was superior to the best of the girdling practices. However, although such trees have been inarched for seven years, and entirely supported by tolerant inarches for five years, they have not completely recovered from quick decline.

These results suggest that the best and most practical procedures to be used in inarching of infected, susceptible trees should include heavy pruning of the tops of the trees and also girdling of the areas between the points of insertion of the in-

arches. By such practices it is probable that trees affected with quick decline can be salvaged by inarching. (Inarching is said to be successful in some parts of Brazil but not in others (*2*).) It should be emphasized, however, that in the present experiments the bearing surfaces of the inarched trees that have made the best responses over a five-year period are not larger than those of young orange trees on tolerant roots that were planted in the same orchards at the time the inarching was done five years ago. The costs of inarching and the care of inarched trees are considerably greater than the costs of removal of the old trees, plus those of purchase, planting, and care.

The effects of inarching healthy trees some years before they become infected with quick decline are as yet unknown. The results obtained in these experiments suggest that some girdling in the area of inarch insertion would be advisable. If the inarches are developed to a relatively large size before the trees are infected with quick decline, it seems probable that the old trees may be salvaged.

It is possible that better material may be found for inarching than the sweet orange and Rough lemon seedlings used in the present experiments. In additional experiments begun in 1948, on healthy trees in an area not yet affected by quick decline, a *Citrus ichangensis* hybrid was most successfully established as an inarch. This agrees with reports by Nagai and Takahashi (*43*) on the use of this species for inarching. According to Bennett and Costa (*2*), Rodriegues indicated that Rangpur lime and sweet lime are preferable for inarching trees affected with tristeza. Bennett and Costa (*2*) suggest that, in Brazil, the inarching of grapefruit trees on sour orange roots is more successful than similar treatment of sweet orange trees on the same roots because of the slower rate of decline of the grapefruit trees.

Bridgegrafting. The use of Rough lemon bridges across the bud union of diseased sweet orange trees on sour orange was not successful. There was a heavy mortality in the grafts, due to drying, in spite of treatment with asphalt emulsion pastes. None of the treated trees gave any evidence of recovery from the symptoms of quick decline, and the progress of the disease was not checked. These results are in agreement with observations by Toxopeus (*55*) and with those given above on the lack of beneficial effects resulting from the use of tolerant interstocks between scions of sweet oranges and susceptible root systems.

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141